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TITLE: A MULTI-CHANNEL, OPTICALLY COUPLED SPARK GAP MONITOR SYSTEM

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A MULTI-CHANNEL OPTICALLY COUPLED LARGE GAP MONITOR SYSTEM

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ABSTRACT

A spark gap monitor system has been installed on PRX-C Large Source Modification, a three plane experiment which forms field-reversed configurations (FRC) using toroids. The field reversing three plane produces a vacuum magnetic field of 150 G inside the single wire, 2-in-long straight 0.7-in-dia coil by discharging in series two 50 kV, 200 pF capacitor banks with a total of 140 2.5-pF capacitors each with a short spark-gap switch and a "piggy-back" overvoltage spark-gap switch. Efficient operation of the bank requires information on the timing and location of each capacitor-spark gap unit. Diagnosing the capacitor-spark-gap unit lead cable current (approximately 20 A per cable) is complicated by the fact that the ground return for the capacitor is of a relatively high impedance. Units that are allowed to prefire or postfire not only degrade the performance of the bank but will self-destruct or destroy their neighbors. To provide this information without introducing high voltage transients into the data acquisition and control system an optically coupled, 140 channel gap monitor system has been installed. Simplicity and reliability were key requirements in the design of the system. A resistor made of thin wall stainless steel tubing replaces a short section of the braid on the lead cable on each capacitor. The voltage developed across the resistor provides the current source to drive an LED. The relatively lower voltage from the LED is transmitted through approximately 30 m of fiber optic cable to the PRX-C control room. The signal is received by a photo diode and simple amplifier circuit that feeds the signal into a 12 channel charge integrating ADC CAMAC module for processing by the computer. The information provided by the system informs the operator as to when and how each gap fired.

System Description

The PRX-C Large Source Modification experiment is powered by a high voltage pulsed power system. The 150 G three plane magnetic field is produced by 140 2.5 pF capacitors charged to 50 kV. Each of the 140 capacitors has a short spark-gap switch and a "piggy-back" overvoltage spark-gap switch. Efficient operation of the experiment requires a delicate adjustment of voltage and timing. A means of monitoring the various systems is essential in order to make these adjustments. Handheld monitors are impractical because of the high voltage transients involved.

Previously Rogowski loops were used to monitor the current in the capacitor bank lead cables. However, since the central lead cables for the bank are not grounded and both conductors are well above ground potential, there were frequent breakdowns between the lead cable conductors and the grounded side of the signal cable. These breakdowns caused serious transients and failures primarily in the receiving electronics, and to some extent in the entire experiment. A fiber optic coupling of the signal eliminates the transients on the monitor system. With the feedback now provided by the fiber optics it is no longer necessary to use the Rogowski loops. A direct measurement of the approximately 20 A current is made by inserting a resistor in series with the length of the lead cable. A voltage is developed across the resistor that is then used as a current source for an LED. The resistor must have very low impedance so as not to interfere with the current being measured, and a relatively high power rating. To survive in the rugged environment that must be provided daily, the transmitter resistor assembly must be compact and rugged. A stainless steel cylindrical resistor was designed to be a continuation of the braid on one of the 6 lead cables from each of the 140 capacitors. This provides a continuation of the central conductor of the cable and still provides the resistance needed, 0.001 Ohm, to drive the current. The resistor is made of 1.5mm O.D., 0.001mm wall No. 30 stainless steel tubing. A copper coupling is also soldered on end and is attached to the top plate of the capacitor spark-gap assembly. The cable braid is chopped on the other end of the resistor. Two right angle copper braids spaced 4.5mm apart longitudinally are also soldered on the cable to increase

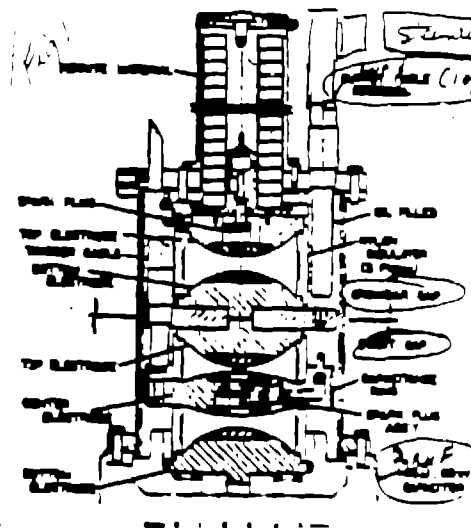


Fig. 1 Drawing of the spark-gap and piggy-back overvoltage gap

for the fiber optic transmitter. Three 1.5mm wide, 4.5mm long slots spaced around the 10mm between the copper braids are machined to increase the resistance for a given length.



Fig. 2 Picture of a section of the PRX-C capacitor bank showing the gap monitor cable.

The copper brackets on the resistor tubing hold and make electrical contact with the transmitter circuit housed in a small Potomac box.

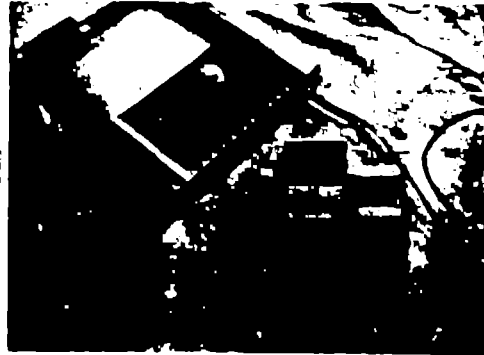


Fig. 3. Picture of two transmitter units with a receiver module.

A fixed 50 Ohm resistor and a 5k potentiometer provide the current for the LED. The potentiometer provides the adjustment (typically 3k Ohm) necessary to offset variations in the transmission of fiber optic assemblies and the LEDs and photodiodes.

TRANSMITTER

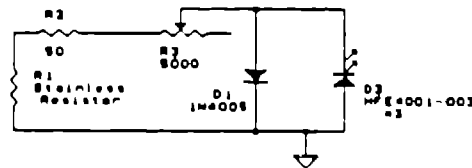


Fig. 4. Schematic of the gap monitor transmitter.

This monitor gives a relative current waveform. The shape of the current waveform is more critical than the absolute value, therefore, an attempt is made for absolute calibration. However, due to the signal amplification for a given channel are reasonably constant so that an absolute calibration is possible if it were necessary.

The fiber optic assembly consists of approximately 30m long, 200-µm diameter fiber optic cables with SMA type terminations. The receiver consists of a photo diode and simple transmitter amplifier circuit capable of driving a 50 Ohm load.

Each receiver circuit is fabricated in a NIM module. The receiver module interfaces with a 12 channel charge integrating ADC CAMAC module for processing by the computer. The charge integrating ADC is gated on for 30ms every 1.6s. The ADC has a 20 word memory. This gives a coarse waveform lasting 60.8s. If an abnormality in the waveform occurs then that channel can be monitored as a faster digitizer.

RECEIVER

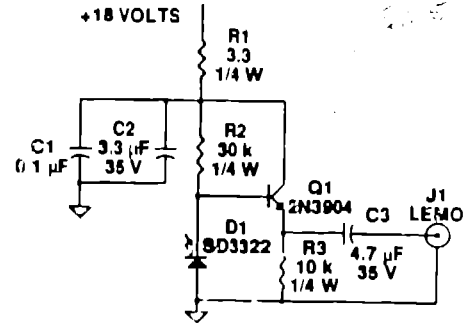


Fig. 5. Schematic of the fiber optic receiver.

for more detail. The charge integrating ADCs were chosen because the cost per channel is significantly less than the faster digitizers with more memory.

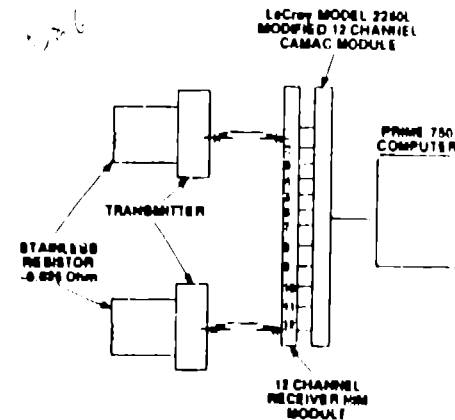


Fig. 6. Block diagram of the gap monitor system.

The resultant waveforms provide the operator with information as to how each of the eight gaps fired and how the monitor functioned. Variations in timing of positions of the capacitor bank triggered by separate submeter trigger units can also be detected. This information is vital to properly tune the system and maintain the efficiency of the monitor operation.

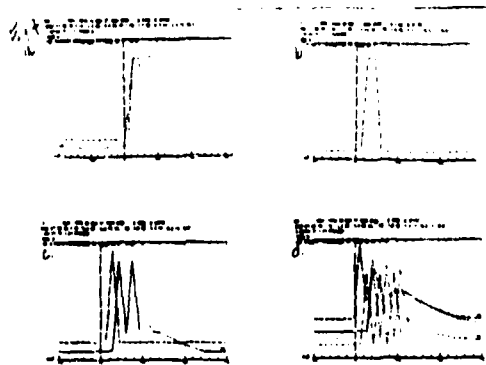


Fig. 7. Raw data waveforms from the gap monitor system.

- a) Two waveforms showing proper function of the gap.
- b) Waveform where crowbar gap did not fire.
- c) Waveforms showing timing malfunction.
- d) Waveforms showing submaster trigger malfunction.

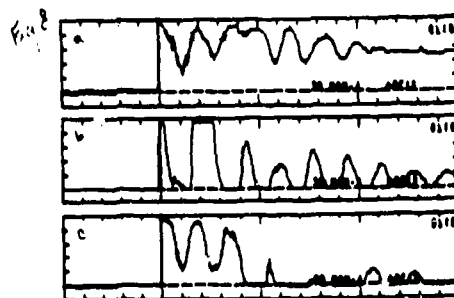


Fig. 8. Gap monitor signals into fast digitizer.

- a) Normal waveform.
- b) Stargap did not fire, crowbar gap did fire.
- c) Crowbar gap did not fire.

- [1] R. W. Kovich, Jr., R. E. Burch, and R. E. Stemon, Proceedings of the 1961 IEEE Conference on Engineering Problems of Fusion Research, New York: IEEE Press, 1961, Publication No. 61CH1715-2, pp. 1751-1754.
- [2] R. W. Kovich, Jr. and D. J. Ray, Summary of Transient High Voltage Calculations for the 20-MV Generator, Los Alamos National Laboratory report LA-2688-1 (June 1962).